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**A PROBE FOR** N64-20584  
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**THE INTERPLANETARY PLASMA**

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A PROBE FOR THE INTERPLANETARY PLASMA

by

(NASA Grant NSG-283)

*Double copy*  
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ABSTRACT

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The energy distributions of protons and other species of ions in interplanetary space as well as at satellite altitudes will be studied using a new detection technique. Observations will be made as a function of time, direction and position over an energy range of at least 10 eV to 10 KeV, with a maximum sensitivity of  $10^{-18}$  A, and the capability to detect single ions. Previous studies of the "solar wind" suggest many important measurements of its state, its interactions with planets, and its wave phenomena. The present instrument, which is  $10 \times 30 \times 20$  (cm<sup>3</sup>) in size, contains an electrostatic energy analyzer, a secondary-electron-scintillation detector, high voltage supplies, and signal conditioning circuits. Laboratory work demonstrates constant response for protons having energies from 30 eV to 3 KeV and a minimum detectable current corresponding to about ten particles per second. Progress is reported on the development of a velocity selector for separating ionic species, hopefully leading to the solution of an important problem in solar wind studies: the determination of the relative abundance of protons and alpha particles.

~~AUTOR~~

## 1. Introduction

Ample evidence now exists for significant particle and energy density in what used to be thought of as "empty space" in the solar system. Even during quiet periods, the solar atmosphere extends to the earth's orbit and beyond in the form of a tenuous, streaming plasma having roughly these properties: number density  $\sim 20$  per  $\text{cm}^3$ , mean velocity  $\sim 5 \times 10^7$  cm/sec, temperature between  $10^5$  and  $10^6$  K. This "solar wind" was first proposed by Biermann<sup>1</sup> and was the subject of subsequent calculations by Parker<sup>2</sup>. Satellite observations by Gringauz et al<sup>3</sup>, Bridge et al<sup>4</sup>, and Neugebauer and Snyder<sup>5</sup> confirm the existence of such a plasma outside the earth's magnetosphere and as distant from us as the orbit of Venus.

Many properties of the solar wind remain unknown, and we are developing a satellite instrument to determine some of them. We hope to define the flow-direction and temperature of the plasma more closely and to examine its composition for the first time. By virtue of high sensitivity, it should be possible to scan the particle energy distributions at various angles with respect to the satellite-sun line and thereby search for anisotropies such as different temperatures parallel and perpendicular to the interplanetary magnetic field. Non-thermal distributions and large changes in plasma composition may be observed following the passage of magnetic storm-fronts.

Previous experiments have enabled some inferences to be made on these subjects, and it should not be taken as a criticism of this work that the evidence is still incomplete in many respects. This testifies instead to the difficulties inherent in (and in many cases peculiar to) space-probe experimentation. The experimenter must strike a balance between the exhaustive measurements he wants to make and the capacity of the vehicle's telemetry system. Such a system can impart information only

so rapidly, particularly when several experiments go on simultaneously. On a long distance flight, such as Mariner, information can only be transmitted at a rate of a few bits per second and one encounters weight and power limitations on the extent to which one can store and process data on-board. We can expect to see several years of successively refined experimentation, before such complex objects as the interplanetary plasma become well understood. Our present work is a step along this way, and we are also developing extensions of the instrument to future work.

## 2. Principles of the Plasma Analyzer and Detector

The analyzer-detector is actually a low energy ion detector, in which mass and energy discrimination are combined to give differential energy spectra of ions with a given value of  $m/Z$ . None of the individual components from which it is made up are original in concept; rather it represents the combination of several known methods into a system which has advantages for operation in space.

(a) In Figure 1 we see a diagram of the system. The ions enter through the slit and are selected differentially in terms of energy-per-unit-charge by the electrostatic analyzer. The  $127^\circ$  deflection configuration is used<sup>6</sup> even though we do not need resolution better than 10% at the present time, both so that we can increase the resolution at any time, and also because it gives a convenient physical arrangement. Equal negative and positive potentials are applied to these plates, and they can either be stepped or driven slowly through a range. In round numbers, that is to say not allowing for fringing effects,

$$E/Z = \frac{R}{d} \times V$$

$R$  = plate radius

$d$  = plate separation

$\pm$  = plate potential

The maximum usable value of  $R/d$  is of order ten. At the same time  $V/d$  must be kept below  $10^4$  in order to avoid certain problems connected with field emission. Thus the maximum practicable value of proton energy which can be measured by this method is approximately 100 KeV, and this is of the same order as the minimum energy which can be detected by a conventional scintillation counter. The two methods are therefore complementary.

(b) Figure 2 shows the result of the analysis of approximately monoenergetic beams of protons. The extractor potential of the ion source is shown for each curve, and it will be seen that the resolution of the analyzer is close to the predicted value. The arrows on the abscissa show the potentials which should be required to detect protons with the nominal potentials shown. The difference between the positions of these arrows and the position of the peaks of current represent the difference between the extraction potential of the ion source and the energy of the resulting ions.

After leaving the analyzer the ions enter a conventional velocity selector of the  $E \times B$  type. The potential applied to the plates is fixed for a given  $m/Z$  and magnetic field  $B$ . In the space application the magnetic field is kept fixed and the deflection cell must be surrounded by a well designed yoke to prevent stray fields from interfering with other experiments on the same satellite. An example of the program of potentials applied to the various electrodes in a specific experiment is given below.

(c) The ions, now belonging to a few species with fixed  $m/Z$  and energy, enter the detecting chamber where they are attracted to a high voltage electrode. This emission knob, made of highly polished aluminum, emits several ( $\sim 3$ ) secondary electrons for each incident ion when maintained at -15 Kv. (7).

These secondaries are accelerated by the same high potential and detected by a plastic scintillator-photomultiplier detector. The scintillator is covered by a thin ( $2000 \text{ \AA}$ ) film of Al which does the double duty of grounding the plastic and keeping visible light from the phototube.

What are actually detected are thus approximately 3 electrons each with 15 KeV energy for each incident ion. These arrive at the scintillator in a time short compared with the resolving time of the output circuit of the tube. The detection efficiency for each 15 KeV electron after it has passed through the Al film is of the order of 50%, and together they give a pulse which is several times higher than the average dark current pulse of the tube. Assuming 50 eV for each photon produced in the plastic scintillator and 5 KeV lost in the Al layer, if we have 50% light collection efficiency and 10% quantum efficiency at the photocathode the average pulse contains

$$G \times \frac{10^4}{50 \times 2} \times 0.1 = 10 \times G \text{ electrons, where } G$$

is the gain of the tube. The efficiency of detecting at least one of three such pulses can be made to be in excess of 80%. The detector thus counts single ions with a high efficiency. Such systems were independently developed by Schutze and Bernhard<sup>8</sup>, Daly<sup>9</sup> and by Afrosimov et al<sup>10</sup>. Eubank and Wilkerson<sup>11</sup> have used the overall analysis and detection system for measuring plasma ion distributions in the laboratory, and Lincke and Wilkerson<sup>12</sup> have used the detector part alone for vacuum-uv spectroscopy.

In Figure 3 we show 3 pulse height analyses for the detector operating in the pulse mode. The ordinate scale is logarithmic and the abscissa represents 256 channels. We note two points

(1) One of the difficulties which we have encountered is in reducing the background counting rate in the absence of ions entering the slit. The rate to be expected due to cosmic rays is of order  $5 \text{ sec}^{-1}$ , but to realize this in practice requires extreme care. The surfaces of the high voltage electrode and the interior of the detecting chamber must be free from dust, since field emission from points can take place when the average field is of order  $10^4 \text{ V/cm}$ <sup>13</sup>. If this occurs it makes itself felt by the presence of a number of pulses at least as large as pulses due to ions. These are seen in the second picture.

(2) The third picture which represents only 1/10 of the counting time of the first two shows the position of the bias level which is set to reduce background. The lack of a distinct peak in the pulse height distribution is due to scattering in the foil covering the plastic scintillator. Although, as noted above, the average pulse at the cathode consists of approximately 10 photoelectrons, the spread is very wide.

We have introduced some refinements in the analyzer-detector for space application. In figure 4 we see a plot of ion and electron trajectories obtained by the conducting paper technique<sup>14</sup> for motion in two dimensions. We find that this electrode shape allows all ions over a wide range of incident energies to strike the knob, and the resulting electrons to reach the scintillator. We have checked this directly by measuring the current gain of the detector as a function of incident proton energy, and find it constant from 100 eV to 3 KeV.

In order to provide a very wide dynamic range of detectable current we proceed as follows. From zero to  $10^5$  pulses per second the pulse-counting mode is used. For higher



incident currents, an electrometer is connected to measure the current from the eighth dynode of the phototube. The dark current to this electrode is of order  $3 \times 10^{-9}$  A, and with overall gain of order  $10^5$  there is some overlap between the two modes of operation. The maximum current which can be recorded in this way is approximately  $10^{-4}$  A, corresponding to an input current of approximately  $10^{-9}$  A. Such a wide range is necessary for studying relative abundances in the solar plasma.

Figures 5 and 6 show photographs of a prototype of this device which is to be flown on an ARGO D-4 rocket to an altitude of about 1000 Km from Wallops Island, Virginia, during September 1963, with the intention both to test its characteristics for space flight and to obtain some information about the ionic constituents of the upper atmosphere<sup>15</sup>.

For this flight only energy-per-unit-charge will be selected, twelve steps between 2 eV and 200 eV being provided. The various parts of the apparatus are indicated in the caption. Figure 6 shows a partially assembled view of the detector system, which weights 7.4 lb. in its present state and consumes approximately 1-1/2 watt at 28 V DC. For satellite use the weight must be reduced, but this should not present an insuperable problem.

The solar plasma comes closely radially from the sun<sup>4</sup> and thus we are interested in counting ions when the entrance angle ( $6^\circ$ ) of the detector includes the radius vector between the sun and the satellite. We must be able to reject visible light and ultraviolet radiation as sources of counts. This problem has not been completely solved, but some of our precautions are shown in Figure 6. Visible light will present the greatest difficulty since the peak of the sun's spectrum is at a wavelength larger than that which can cause the emission of electrons from the Al knob. Thus the visible light must be

prevented from entering the detection chamber, and that which does so must then be prevented from entering the phototube. The thickness of the Al layer on the scintillator is fixed, since 5 KeV is the maximum acceptable mean energy loss for electrons passing through it. The purpose of the horn type light absorber<sup>16</sup> is to prevent light passing through the metal gauze window in the outer plate from re-entering the box around the analyzer. The principal variable is the degree to which light scattered from the metal gauze can penetrate to the box. This and the presently unknown ultraviolet sensitivity may limit the usefulness of the device, but work is at present proceeding on both these subjects. Providing one does not look directly in the direction of the sun, the present rocket experiment gives no indication of visible light.

The development and testing of the detector has been carried out using a vacuum system in which we have incorporated an RF ion source. By introducing hydrogen through a Palladium leak, we produce a beam consisting principally of protons. By separating the detector from the source by a distance of order 1-2 meters a uniform beam of particles may be obtained capable of filling the slit of the analyzer. Current measurements are carried out using Faraday cups, and current division can be carried out to a fair degree of accuracy by such cups with a small hole in the bottom, if stops are introduced at the correct places in the ion beam. The use of electrons, for which one knows the energy accurately, is possible by substituting suitable guns for the ion source, and these were used to obtain the energy profile of the energy per unit charge analyzer shown in Figure 7. The detector is mounted inside the vacuum on a system of motor-driven tables, allowing both rotation about the axis of the defining slit and translation across the beam axis. This is used to check the solid angle of acceptance of the system, at present  $6^{\circ} \times 6^{\circ}$  approximately.

### 3. Specific Satellite Experiment

We conclude by discussing an experiment we have proposed for a class of satellites having orbits with apogee exceeding 40 earth radii, so that one can therefore observe the solar wind well outside its region of interaction with the earth's magnetic field. Because of the telemetry limitations, the experiment must be simplified a great deal compared to its potential complexity. Specifically we will study four bands E/Z ( $E = 200, 400, 800, 1600$  eV for protons) and five bands in m/Z (1, 1.5, 2, 3 and 4) in each E/Z channel. Altogether then, there are  $4 \times 5 = 20$  categories of particle data to be scanned repetitively in a given sequence. Each category is examined for one revolution of the spacecraft, and the total count, or total received charge, during the revolution is the datum we record. The satellite will spin about an axis approximately at right angles to the plane of the ecliptic.

The experiment will be mounted equatorially on the satellite; i.e., it will see only that portion of the sky lying in a shallow pillbox which includes the solar direction. Since we integrate the signal over a revolution our data are the azimuthal integrals of particle flux over this rotating cone, and we sacrifice all angular resolution with respect to the satellite-sun line. Such a sacrifice is made reluctantly, but we have decided to use all of the telemetry capacity for what seems to be a much more important matter at this time - namely the examination of the solar plasma for its ionic constituents.

Velocity channels have been chosen to bracket what is believed to be the mean speed of the solar wind. The bulk of the plasma is probably to be found in this range because of its relatively low temperature compared to its energy of ordered motion. The channels in m/Z (+7% precision) will

isolate protons from all other species, enable a search for  $\text{He}^3$ , present a sum of abundances for alpha-particles and many other nuclides at  $m/Z = 2$ , and give two samples ( $m/Z = 3$  and  $4$ ) of the flux of partially - ionized atoms.

Clearly, high resolution will someday be required in view of the many constituents likely to be present in the interplanetary plasma. The work of Nier<sup>17</sup> illustrates the developments in this field. We regard our lower resolution experiment as a necessary first step to assess the degree to which the mass spectrum may vary with the range of particle energy considered.

#### 4. Other Experiments

Apart from the sounding rocket and satellite measurements we have discussed, many other experiments are possible with this apparatus depending on the satellite orbit. The most important appears to be to study the structure of the sun-ward boundary between the earth's magnetic field and the solar wind. A satellite such as EGO would be appropriate since its orbit is designed for repetitive transits into and out of the magnetosphere.

Orbits of greater eccentricity than that of EGO may provide an opportunity to study the "standing shock" which some theoreticians<sup>18</sup> believe to be the result of interaction between gas reflected from the magnetosphere and the incoming solar wind. By picking out the proton component, for example, and recording energy distributions as a function of position and angle, we would find density and temperature profiles in the plasma over some depth in the interface region.

#### 5. Acknowledgements

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We are also grateful for advice and help from H. P. Eubank and F. B. McDonald, who independently suggested the analyzer-detector combination. We also wish to thank Lee Terry for his valuable technical assistance.

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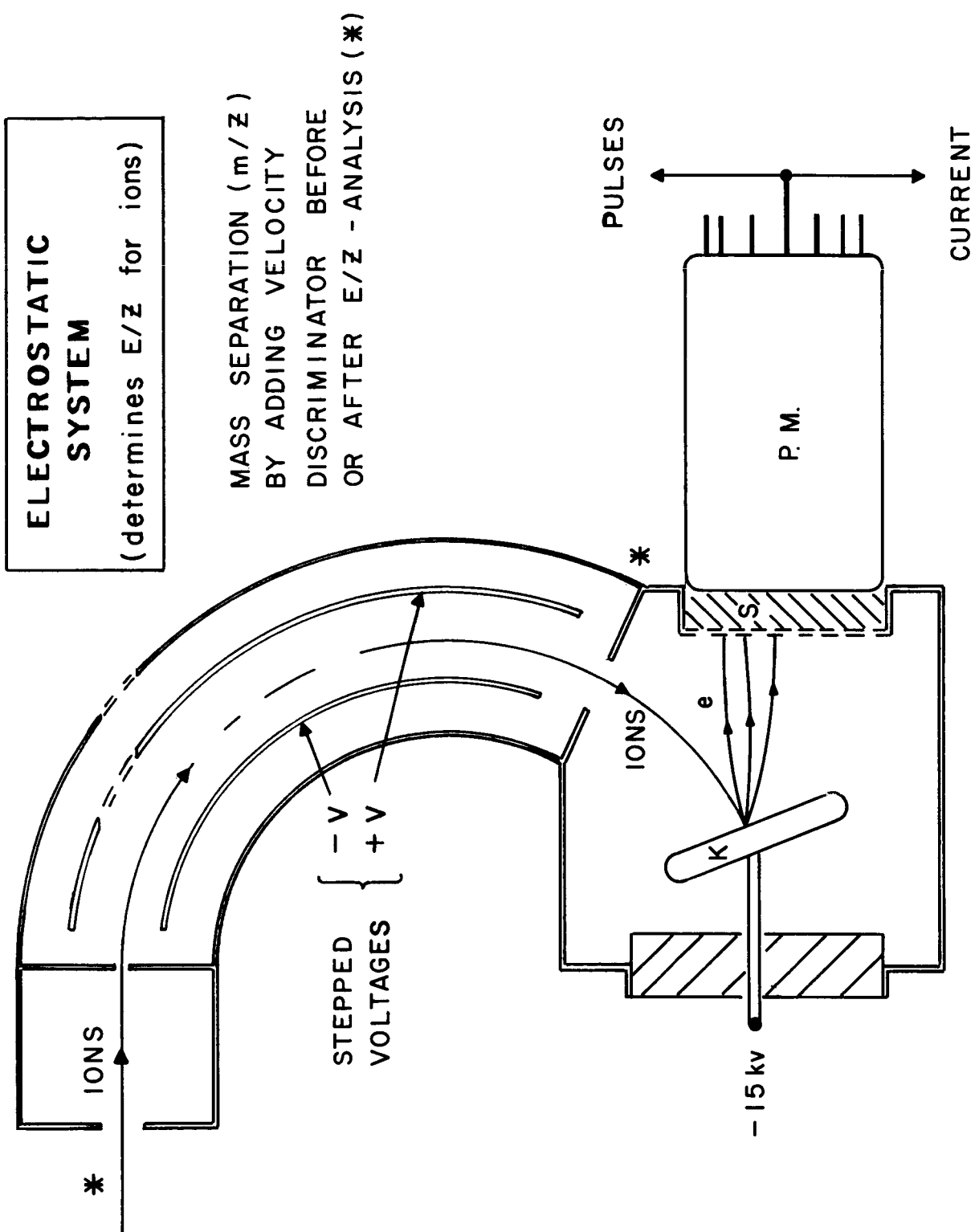
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## FIGURE CAPTIONS

- Fig. 1 - The energy per unit charge instrument is shown in this diagram. The velocity selector will be inserted between the analyzer and the detector box.
- Fig. 2 - The result of analysis of approximately monoenergetic beams of protons. The figures attached to each curve show the extractor potential applied to the ion source. The deflector plate potential for selecting a proton of energy  $E$  is  $E/4$  volts.
- Fig. 3 - Pulse height analyses for the detector. The ordinate is logarithmic and the abscissa is 256 channels.
- Fig. 4 - Equipotentials and trajectories for ions and electrons.
- Fig. 5 - Prototype energy per unit charge analyzer for rocket flight test.
- Fig. 6 - Partially assembled view of the rocket instrument.
- Fig. 7 - The energy profile of the analyzer, measured using electrons.



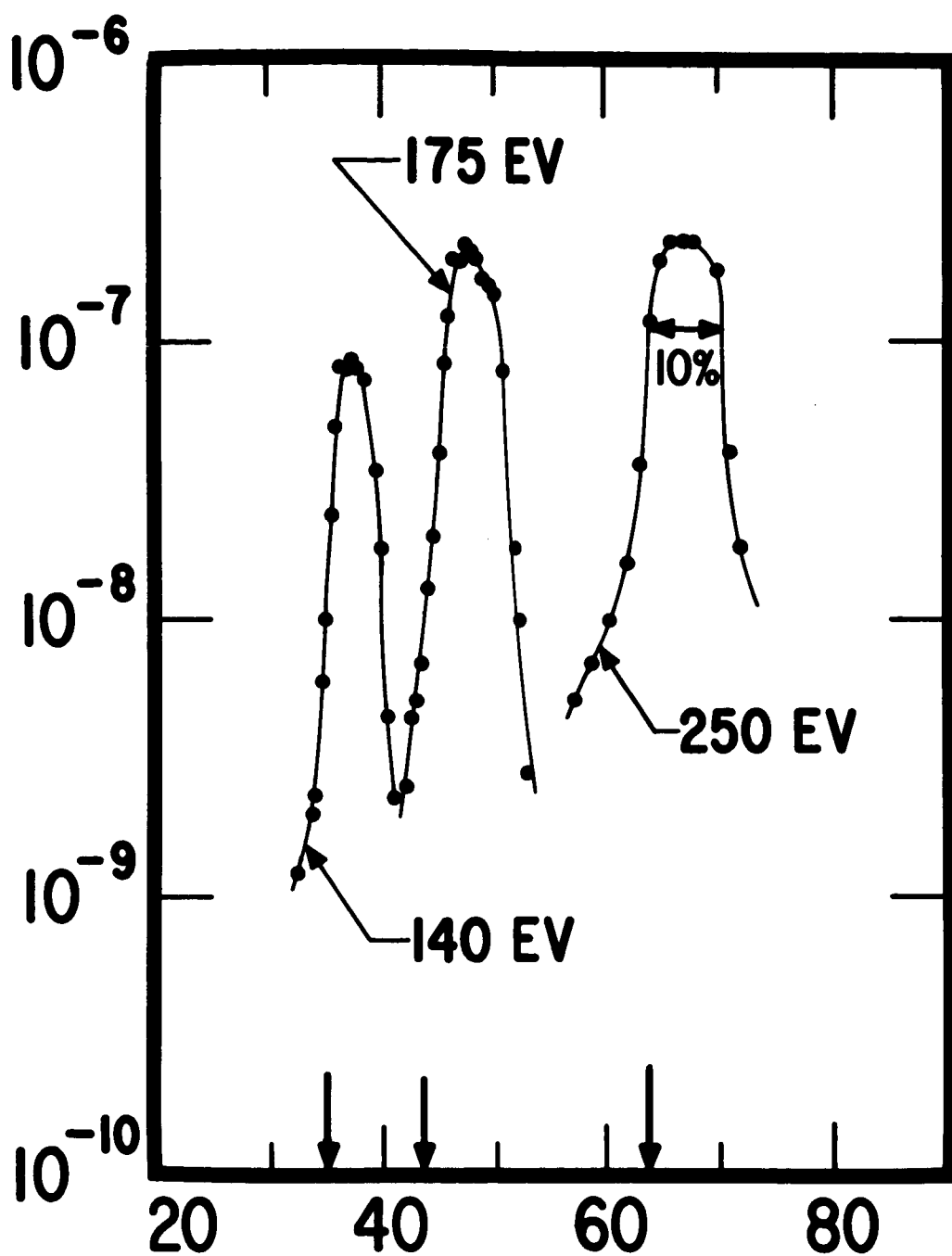


**ELECTROSTATIC SYSTEM**

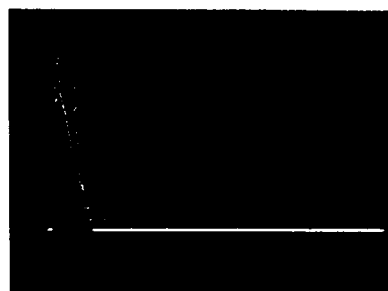
(determines  $E/Z$  for ions)

MASS SEPARATION ( $m/Z$ )  
BY ADDING VELOCITY  
DISCRIMINATOR BEFORE  
OR AFTER  $E/Z$  - ANALYSIS (\*)

PHOTOTUBE CURRENT

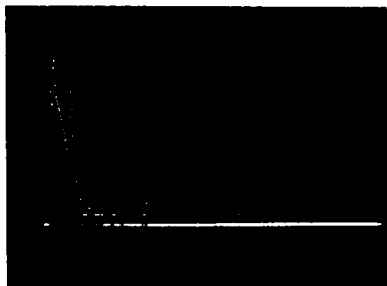


DEFLECTOR PLATE POTENTIAL



**PHOTO TUBE  
BACKGROUND**

↑  
**NO. OF  
PULSES**



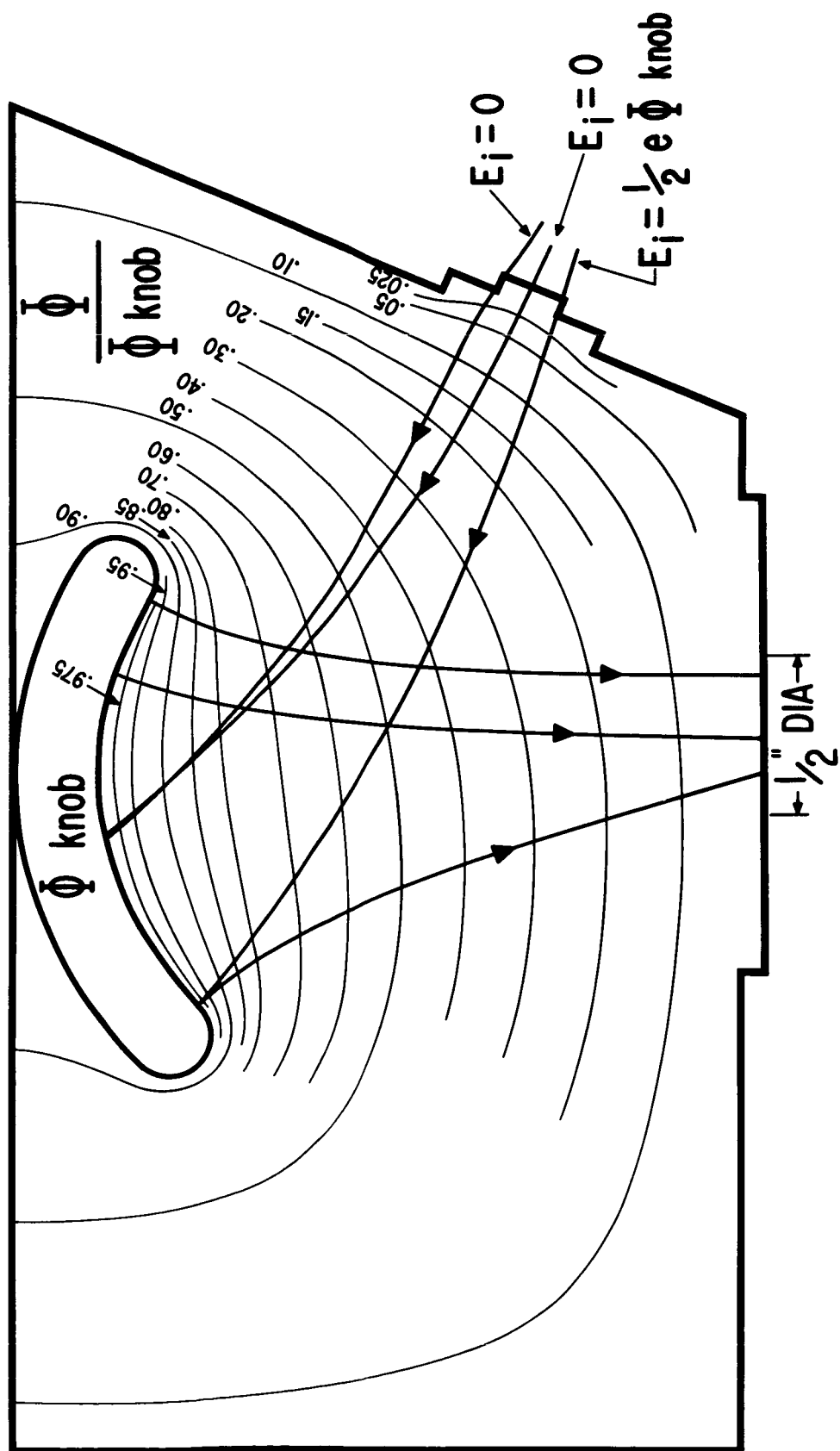
**TOTAL  
BACKGROUND**

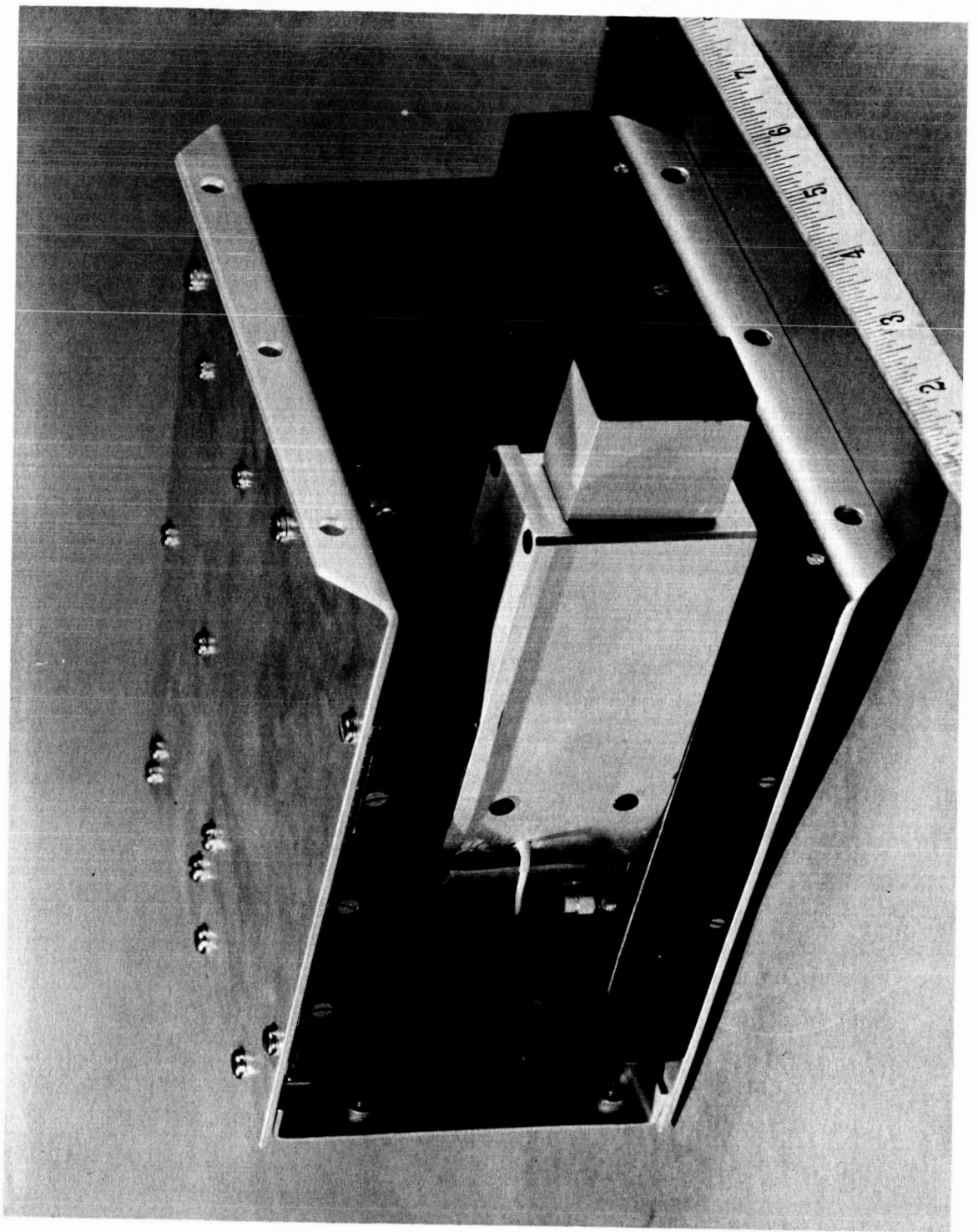


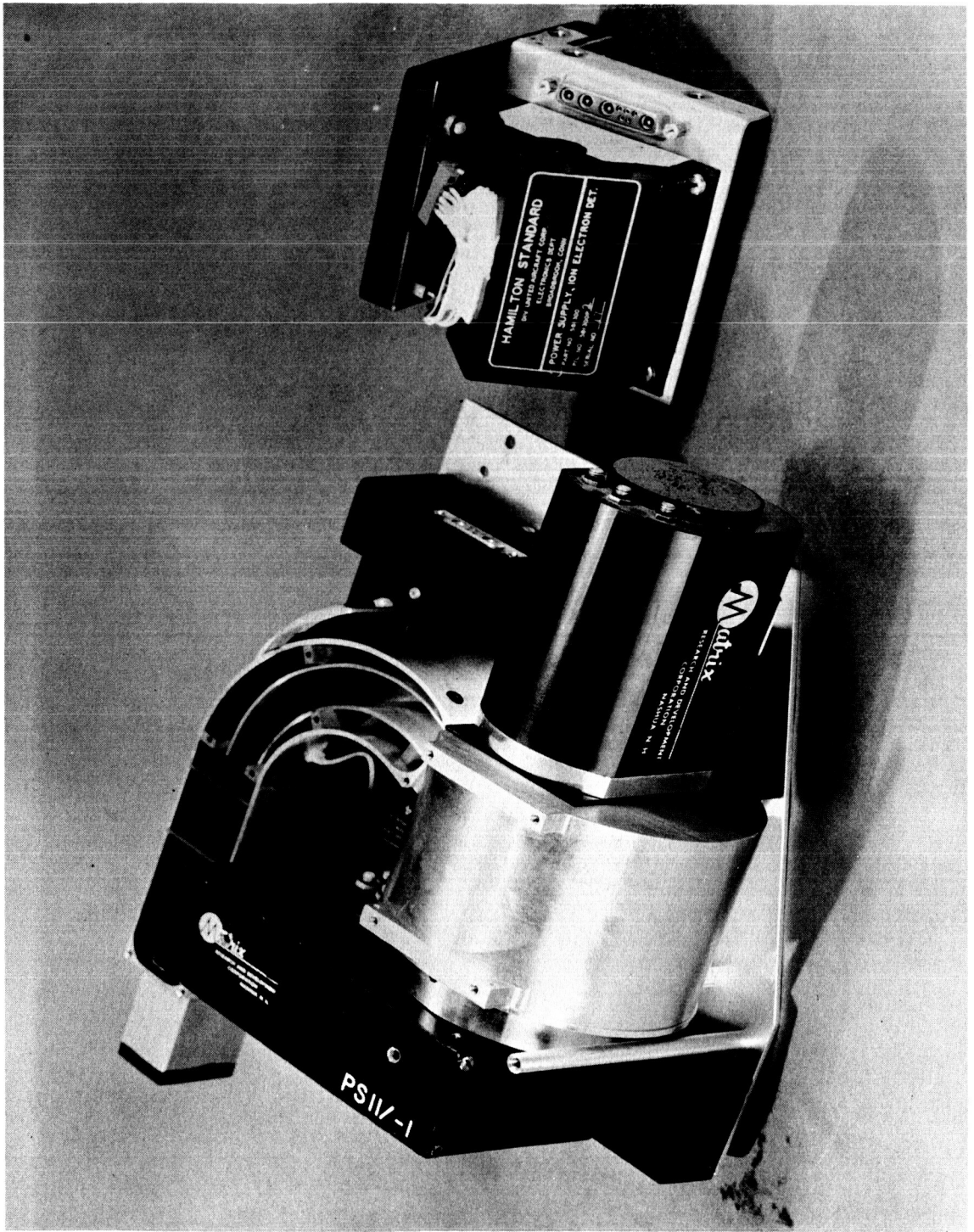
**400 EV  
PROTONS  
&  
BACKGROUND**

↑  
**BIAS LEVEL**

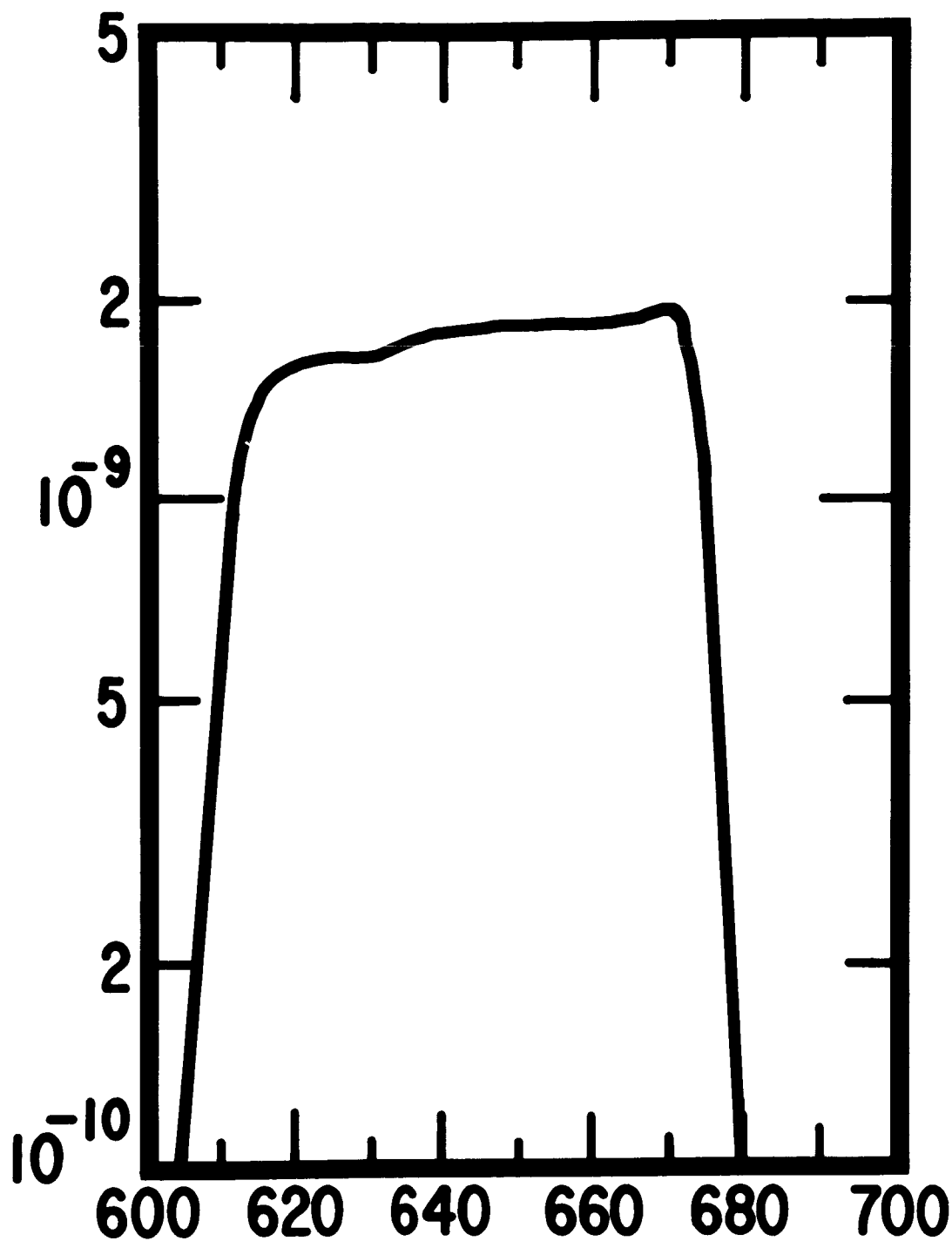
→ **CHANNEL  
NUMBER**







**OUTPUT CURRENT**



**BEAM ENERGY**